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Demonstrating the Automated Change Detection and Classification (ACDC) System during the Gulf of Mexico FY05 Naval Exercise (GOMEX-05)

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14. ABSTRACT

   This report presents test results from a demonstration of the Automated Change Detection and Classification (ACDC) system, developed by the Naval Research Laboratory (NRL) in support of sidescan sonar analysts at the Naval Oceanographic Office. NRL compared the computer-aided change detecction capabilities of ACDC with traditional, manual methods of change detection during a naval mine warfare exercise in 2004. Two versions of ACDC (ACDC "Lite" and "Medium") were tested to determine how well the system could aid analysts in detecting changes between newly collected sidescan sonar imagery and historical imagery. ACDC Lite enabled analysts to perform change detection significantly faster than manual methods (3.36 min. vs 2 hr) with identical results. ACDC Medium improved analysts' performance by matching one additional contact during change detection, in as little as 12.6 min. Follow-on work is suggested for further improving ACDC performance in support of mine countermeasures.

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DEMONSTRATING THE AUTOMATED CHANGE DETECTION AND CLASSIFICATION (ACDC) SYSTEM DURING THE GULF OF MEXICO FY05 NAVAL EXERCISE (GOMEX-05)

1. INTRODUCTION

The Naval Oceanographic Office (NAVOCEANO) participated in the Gulf of Mexico Mine Warfare Exercise 05-1 (GOMEX) on December 3 through 14, 2004 in Panama City, Florida, in support of Mine Countermeasures (MCM) Squadron 3, Helicopter Mine Countermeasures Squadrons 14 and 15 (HM-14/15), Meteorology and Oceanography Support Commander, and the Commander Mine Warfare Command. Sensors employed by the HM squadrons were the helicopter-towed mine hunting sidescan sonar systems AN/AQS-14A and AN/AQS-24.

The Naval Research Laboratory (NRL) tested their Automated Change Detection and Classification (ACDC) system during GOMEX as a "reach-back" capability to aid NAVOCEANO sidescan sonar analysts performing change detection between historical and newly collected sidescan imagery. The historical imagery was collected by NAVOCEANO in November 2004 and stored in the NAVOCEANO Master Contact Database (MCDB). New imagery was collected over the same geographic area during GOMEX. Several inert mines were laid in this area at the start of the exercise to test the ability of squadron operators to find mines during post-mission analysis (PMA). Since NAVOCEANO had historical sidescan data of the same geographic area before the inert mines where laid, change detection also could be tested.

This report describes the testing procedures and preliminary results of NRL ACDC demonstrations, the purpose of which was to determine whether this system could aid sidescan sonar analysts to more quickly identify contacts in the new imagery that also existed in the historical imagery (i.e., perform change detection). Analysts using ACDC were expected to identify at least as many preexisting contacts as analysts using manual methods alone. NRL tested ACDC with NAVOCEANO analysts located at the Stennis Space Center, Mississippi, in a reach-back mode during GOMEX, due to a lack of funding for an on-site demonstration.

Following this introduction section, Section 2 provides an overview of the ACDC system, including a brief description of its principal algorithm components. Section 3 describes the process of manual change detection as it is currently performed by sidescan sonar operators and analysts. Section 4 describes the process of automated or computer-aided change detection, as performed by analysts using ACDC during GOMEX. Section 5 documents the tests performed with ACDC during GOMEX, including the test objectives, methods, and results. Section 6 summarizes this report and suggests future work.

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2. ACDC SYSTEM

Speeding up the "detect to engagement" timeline in a mine warfare environment is central to the Sea Shield concept for achieving littoral sea control and assured access. In recent years, considerable effort has been applied through the Chief of Naval Operations (CNO) N75 Mine Warfare (MIW) Campaign Plan to develop robust environmental databases that rely on high-resolution sidescan sonar imagery for developing doctrinal bottom types and mine-like contact databases for ingest into the Mine Warfare Environmental Decisions Aid Library (MEDAL). The use of "change detection" to determine the presence or absence of mines has become a critical tactical tool in MCM operations by reducing mine clearance timelines and developing an accurate assessment of risk to follow-on naval forces.

Manual change detection is performed either on-scene or via reach-back to NAVOCEANO. However, with the integration of numerous organic MIW sensors in the battle group, including onboard future Littoral Combat Ship mission modules, automated algorithms to support on-scene, in-stride change detection must be developed and implemented in the Fleet. In FY03, NRL initiated development of ACDC to provide this Fleet capability (Gendron et al. 2004).

The long-term goal of the ACDC project is to provide automated change detection capabilities to the MCM warfighter, which will help to reduce warfighter fatigue and risk to the warfighter, and shorten timelines for completion of MCM objectives. To realize this goal, NRL has been developing, validating, and verifying component algorithms in support of a fully functional ACDC system for sidescan imagery to NAVOCEANO.

ACDC consists of six major components: clutter detection, feature completion, computer-aided search (CAS), feature matching, scene matching, and clustering. Depending on the quality of sidescan imagery to be analyzed, each of these steps can be performed autonomously (i.e., with no human intervention) or as a computer-assisted function (in which ACDC suggests statistically likely outcomes to an analyst, who makes a final determination).

To date, four of the six components have been developed: the clutter detection, feature completion, CAS, and clustering algorithms. Manuscript approved January 26, 2005. These algorithms currently are stand-alone, command-line software applications that are not yet configured within a graphical user interface (GUI). To complete ACDC, NRL has proposed to develop the remaining feature- and scene-matching algorithms and to combine all six algorithms into one user-friendly GUI. The following paragraphs describe each ACDC component in more detail.

2.1 Clutter Detection

Mine-like objects (MLOs), or simply clutter, show up in sidescan sonar imagery as bright spots, with adjacent shadows facing perpendicularly away from the center of the scan track, or nadir. ACDC includes a real-time algorithm that detects these bright spots and shadows. The operator then manually reviews the objects and selects those to be processed further.

2.2 Feature Completion

Features of various shapes and sizes are traditionally discerned in sidescan by the shadow's dimensions, which vary as a function of both grazing angle and feature size (Fish and Carr 1990). Shadows are detected more easily and reliably than bright spots in sidescan; bright spots often appear smaller or larger than the actual object. ACDC corrects this using an adaptive filter to "complete" the feature's bright spot, reducing or enlarging it based on the shadow, and generates a confidence measure. The feature then can be classified more accurately using dimensions of both the shadow and completed bright spot. The filter outputs the confidence measure and a snippet of imagery that contains only three grayscale values: black for shadow bits, white for completed bright spot bits, and gray for all other bits.

2.3 Computer-Aided Search

The ACDC CAS algorithm searches historical databases, such as the NAVOCEANO MCDB, to find previously detected features that are spatially close to each newly detected feature. The MCDB contains imagery from past sidescan surveys, along with snippets and descriptive attributes of classified features from those surveys. The search algorithm attempts to match each newly detected feature with spatially close historical features while correcting for estimated position errors (e.g., feature migration and Global Positioning System errors) in both the new and historical features. If no matches are successful, then the newly detected feature is marked as a new object not seen before in the historical data. If a single match is made (i.e., one historical feature matches the new feature), they are assumed to be the same. If more than one historical feature matches a new feature, ACDC passes the new feature and all possible historical matching features to the next phase of processing.

2.4 Feature and Scene Matching

The final phase of ACDC (which NRL has proposed to complete in FY05-06) includes the development of two automated algorithms. A *feature-matching* algorithm will input wavelet coefficients to a neural network and match historical features (extracted during CAS) with newly detected features. Wavelet networks have been proven to match complex features well, e.g., in face recognition (Krueger and Sommer 2000). To reduce the numerous false detections common during feature matching, a *scene-matching* algorithm will match bounded regions of clustered features with corresponding regions of historical features, using another wavelet network and a single-pass clustering algorithm, described below.

2.5 Clustering

The authors have developed a fast, efficient, and repeatable clustering algorithm (Gendron et al. submitted) to cluster geospatially close contacts and determine "clutter density." The clustering is accomplished by mapping each contact into one or more predefined geometric "expansion shapes" using geospatial bitmaps (GBs). The GB clustering algorithm is a good choice for applications that require automated clustering in real-time: it is single-pass (i.e., noniterative), requires no seed points, and is order-independent (i.e., the ordering of elements has no effect on the resultant clusters). In addition to clustering the elements, the algorithm produces a bounded polygon to define each cluster boundary and calculates a measure of clutter density, which is the number of clustered elements divided by the area of the cluster polygon. ACDC uses this clustering algorithm to identify regions of high-, medium-, and low-clutter density in sidescan. MCM warfighters use clutter density to determine whether an area of interest should be swept for mines prior to an operation and to estimate the amount of time and resources needed to clear an area of mines.

3. MANUAL CHANGE DETECTION

Prior to change detection, operators detect and classify contacts during PMA of the newly collected mission data. Contacts identified during PMA are referred to as "PMA contacts" in this report. Following this process, NAVOCEANO analysts perform change detection to determine whether any of the PMA contacts existed during previous surveys. NAVOCEANO has identified three methods by which their analysts perform manual change detection: "lite," "medium," and "heavy." Change detection "lite" is the quickest but least accurate of the methods; change detection "heavy" is the slowest, but most accurate. Change detection "medium" is a compromise solution. Each method is detailed below.

3.1 Change Detection Lite (comparing PMA *snippet* to historical *snippet*)

An analyst searches the MCDB for snippets of contacts that are spatially close to the latitude and longitude (LAT/LON) location of each individual PMA contact. The analyst then makes a visual comparison between a snippet of the PMA contact and snippets of each spatially close contact in the MCDB. This method requires the MCDB to be populated with snippets for all MLOs in the area of interest (AOI).

3.2 Change Detection Medium (comparing PMA *snippet* to historical *imagery*)

An analyst searches historical imagery for contacts that are spatially close to the LAT/LON location of each individual PMA contact. The analyst then makes a visual comparison between the PMA contact snippet and the geospatially close regions within the historical imagery. If a match is found, the analyst manually creates a snippet of the historical contact. This method assumes that the MCDB may not have been populated with snippets of all MLOs in the AOI.

3.3 Change Detection Heavy (comparing new *imagery* to historical *imagery*)

An analyst reviews the newly collected imagery to verify the LAT/LON location of the PMA contact. The analyst then searches the historical imagery for all contacts that are spatially close to that location and performs a side-by-side visual comparison between the images, attempting to match both individual features and configurations of surrounding features (i.e., "scene matching") to increase confidence in the match.

4. AUTOMATED CHANGE DETECTION

ACDC will provide the same three levels of processing. During GOMEX, NRL tested the ACDC Lite and Medium methods; ACDC Heavy will be completed with additional funding (see Plans, below).

4.1 ACDC Lite (comparing PMA *snippet* to historical *snippet*)

An analyst runs the ACDC CAS algorithm, which searches the MCDB for snippets of historical contacts that are spatially close to the LAT/LON location of each individual PMA contact. ACDC then displays to the analyst each historical contact snippet adjacent to the PMA contact snippet and prompts the analyst for a change detection decision: yes (i.e., these snippets represent the same contact) or no (these are different contacts). ACDC stores the results in a Hypertext Markup Language (HTML) file that can be viewed later by MCM staff.

4.2 ACDC Medium (comparing PMA *snippet* to historical *imagery*)

An analyst runs ACDC to create a list of the LAT/LON locations of all MLO within the historical imagery. The analyst then runs the ACDC CAS algorithm to search the historical list for contacts that are spatially close to each individual PMA contact. For each potential match, ACDC carves out a snippet from the historical imagery and executes the ACDC feature completion algorithm, which attempts to "complete" the contact. ACDC then either rejects the contact as a false detection or displays the contact to the analyst as a snippet adjacent to the PMA contact snippet, along with a confidence measure, and prompts the analyst for a change detection decision, as in the Lite method. ACDC stores the results in an HTML file that can be viewed later by MCM staff.

4.3 ACDC Heavy (comparing new *imagery* to historical *imagery*)

When this method is completed, an analyst will be able to run ACDC to create one list of the LAT/LON locations of all MLO within the historical imagery and a second list of the LAT/LON locations of all MLO within the newly collected imagery. ACDC will input the LAT/LON location of each PMA contact, display the new imagery surrounding that contact location and highlight the PMA contact in the imagery. ACDC will also display the historical imagery surrounding that contact location, and highlight all MLOs in the region. ACDC feature-matching and scene-matching algorithms will attempt to match the PMA contact in the new imagery with the geospatially close MLOs in the historical imagery. ACDC will present all potential matches and associated confidence measures to the analyst, who will make the final decision.

5. ACDC DEMONSTRATION (GOMEX-05)

5.1 Objectives

NRL and NAVOCEANO objectives during this exercise were to test and demonstrate the following ACDC capabilities:

1. ACDC Lite: ability to aid analysts in spatially searching snippets in the historical MCDB for each of 13 contacts manually detected during PMA that were in the same geographic region as the historical data.

2. ACDC Medium: ability to detect MLOs in 32 historical Unified Sonar Image Processing System (UNISIPS) imagery files, spatially search the historical contacts for each of the 13 PMA contacts (described above), and display results to the analyst.

3. ACDC parallel processing: benchmark ACDC algorithms on the NAVOCEANO single-CPU prototype Bottom Mapping Workstation (BMW) and compare processing times with a parallel version of ACDC running on a new four-CPU "next generation" BMW.

5.2 Methods

5.2.1 Data Collected

Helicopter Mine Countermeasures (HM) squadrons completed more than 15 missions during GOMEX. Several inert mines were laid in this area at the start of the exercise to test the ability of squadron operators to find mines during PMA. Since NAVOCEANO had historical sidescan data of the same geographic area before the inert mines were laid, change detection could be performed.

5.2.2 Software and Hardware System Integration

Prior to GOMEX, the authors wrote command-line software to link the four existing ACDC algorithms in preparation for testing ACDC Lite, ACDC Medium, ACDC detection, and ACDC parallel processing. NRL scientists installed the software on the prototype and next-generation BMW systems:

Prototype BMW:

- Single CPU Intel, 1.1 GHz, 512 Mbytes RAM
- Linux Operating System

Next Generation BMW (Fig. 1):

- Four CPU Intel, 3.1 GHz, 1 Gbytes RAM
- Linux Operation System

5.2.3 Tests Performed

During GOMEX, NAVOCEANO analysts performed change detection using both traditional (manual) and computer-aided (ACDC Lite and Medium) methods on the NAVOCEANO BMW systems. Results were recorded for the following comparisons:

1. Manual change detection on the prototype BMW

2. ACDC Lite change detection on the prototype BMW

3. ACDC Medium on the prototype BMW

4. ACDC Medium on four configurations of the next generation BMW: one CPU, two CPUs, three CPUs, and four CPUs. The last three configurations used a parallel processing version of ACDC that took advantage of the multiple CPUs to reduce computation times.

Fig. 1 — Next generation BMW

5. 3 Results

Table 1 presents results of manual and computer-aided change detection tests performed by NAVOCEANO analysts during GOMEX. Snippets of the contacts and supporting figures will be included in a confidential report being prepared by NAVOCEANO.

Table 1— Change Detection Results and Benchmarks

| | | | | Time to perform change detection on BMW systems: | | | | |
| | | | | Prototype | New | New | New | New |
Method	C	M	R	(1 CPU)	(1 CPU)	(2 CPUs)	(3 CPUs)	(4 CPUs)
Manual	13	4	9	~120 min	–	–	–	–
ACDC-Lite	13	4	9	3.37 min	–	–	–	–
ACDC-Med	13	5	8	33.80 min	19.77 min	14.83 min	13.39 min	12.60 min

C: #PMA contacts found by squadron operators in the same region as historical imagery
M: #PMA contacts matched by NAVOCEANO analysts with historical contacts
R: #PMA contacts remaining to be investigated to ensure they are not mines

5.3.1 Manual Change Detection

As shown in Table 1, it took approximately 2 hr for NAVOCEANO analysts to perform manual change detection on the GOMEX data. (The exact time will be provided in a confidential report being prepared by NAVOCEANO.) Analysts matched 4 out of 13 PMA contacts from the GOMEX data with contacts in historical imagery.

5.3.2 ACDC Lite (comparing PMA *snippet* to historical *snippet*)

It took 3.37 min. for NAVOCEANO analysts using ACDC Lite to match the same 4 out of 13 PMA contacts (shown as snippets) from the GOMEX data with contacts (also shown as snippets) in the historical MCDB. Note that ACDC Lite does not preprocess the historical imagery. ACDC recorded the results to an HTML file, which will be presented in the NAVOCEANO confidential report.

5.3.3 ACDC Medium (comparing PMA *snippet* to historical *imagery*)

It took 24.56 min. for ACDC Medium to process historical imagery and flag historical MLOs using the prototype BMW. The next section compares processing times for ACDC on the prototype BMW with the new parallel processing BMW. It took an additional 9.24 min. (for a total of 33.8 min., shown in table 1) for NAVOCEANO analysts using ACDC to match the same 4 out of 13 PMA contacts (shown as snippets) plus an additional contact. ACDC recorded the results to an HTML file, which will be presented in the NAVOCEANO confidential report.

5.3.4 ACDC Parallel Processing

Figure 2 presents the processing times (in minutes) for ACDC to flag MLOs in historical imagery (consisting of 32 UNISIPS files) using five BMW system configurations. The four-CPU configuration sped up this process by more than 7:1 over the original prototype BMW.
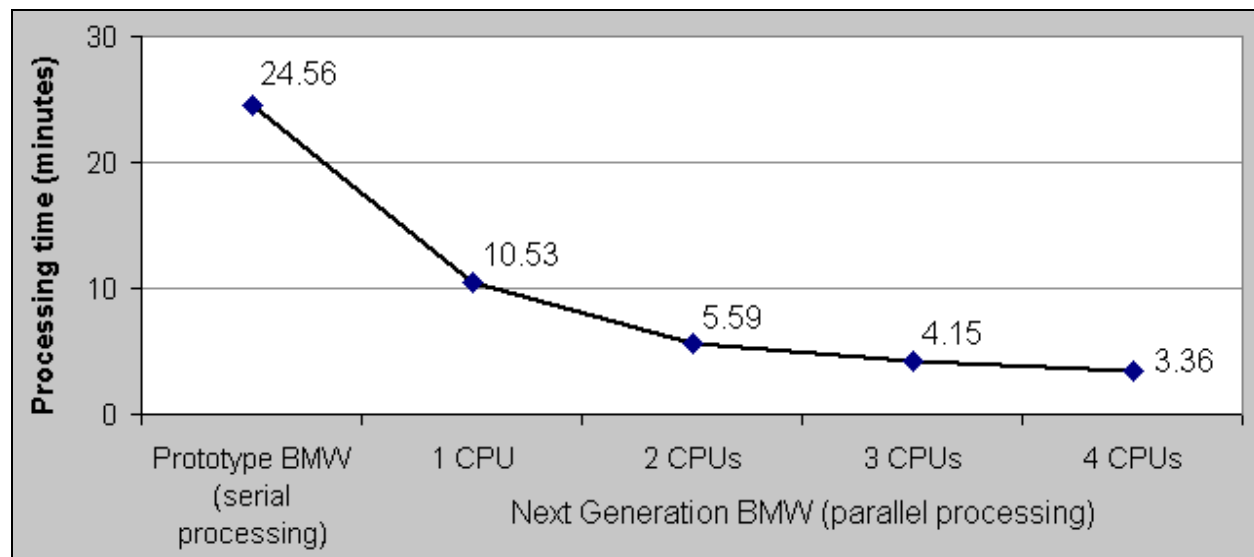
Fig. 2 — Time (minutes) for ACDC to process 32 historical UNISIPS files

6. SUMMARY

This demonstration has shown that ACDC can aid analysts in performing change detection more quickly and efficiently than manual methods alone. Specifically, ACDC Lite enabled analysts to perform change detection significantly faster (3.36 min. compared to 2 hr) with identical results. ACDC Medium improved analysts' performance by matching one additional contact during change detection, in as little as 12.6 min. with four CPUs.

The current ACDC running in parallel on the new BMW using all four processors can process UNISIPS sidescan imagery at a rate of less than 1 min. per hr of mission data (assuming one UNISIPS file contains about 10 min. of mission data). If resources are made available to complete the parallel feature- and scene-matching algorithms for ACDC, ACDC Heavy could be developed to further improve change detection performance.

During ACDC Medium testing, the analysts encountered numerous false detections, which slowed analysis but did not impact final change detection results. The majority of these false detections were found to be sand ridges on the seafloor.

In support of GOMEX, NRL pieced together preliminary versions of ACDC Lite and Medium as command-line-driven functions with hard-coded data input files and other parameters. Before ACDC could be transitioned to NAVOCEANO or even implemented for other data sets, NRL must finalize the existing algorithms and incorporate them into a GUI. Specifically, the following issues must be addressed in future ACDC development at NRL: automated feature- and scene-matching algorithms, minimizing false detections, configuring the ACDC algorithms into a user-friendly GUI, and performing validation/verification on ACDC.

7. ACKNOWLEDGMENTS

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GLOSSARY

ACDC	Automated Change Detection and Classification
AOI	Area of interest
BMW	Bottom mapping workstation
CAS	Computer-aided search
GB	Geospatial bitmap
GOMEX	Gulf of Mexico Mine Warfare Exercise 05-1
GUI	Graphical user interface
HM	Helicopter mine countermeasures
HTML	Hypertext Markup Language
LAT/LON	Latitude and longitude
MCDB	Master contact database
MCM	Mine countermeasures
MEDAL	Mine Warfare Environmental Decisions Aid Library
MIW	Mine warfare
MLO	Mine-like object
NAVOCEANO	Naval Oceanographic Office
NRL	Naval Research Laboratory
ONR	Office of Naval Research
PMA	Post-mission analysis
UNISIPS	Unified Sonar Image Processing System